

## **Reusing Vehicle Simulation Software – Mission Impossible?**

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### **ABSTRACT**

Software reuse is an admirable goal that has many warts in application. This paper discusses one experience in reusing a large suite of simulation code in a significantly different environment. Tank-Automotive Research, Development and Engineering Center (TARDEC) Vetronics research programs developed over several years a significant body of vehicle embedded simulation system (ESS) software. TARDEC continues to evolve this ESS to meet the simulation needs of the Future Combat Systems (FCS). The US Army Research Development and Engineering Command's (RDECOM) Simulation Technology Center (STC) was interested in reusing this software for crewstations being considered for an embedded training and mission rehearsal testbed. This paper discusses the STC experience in reusing TARDEC's ESS software. The paper provides background on the software in question and its intended uses by both organizations. It addresses some of the issues encountered in reuse, such as the difficulty in understanding the volume of code involved and hardware and software dependencies. The paper goes on to discuss the tradeoffs that evolved from these issues and the resulting decisions that affected software adaptation. Finally, the paper concludes with a discussion of plans for continued adaptation of ESS software for STC use and a review of program successes.

### **INTRODUCTION**

For the past several years both the Vetronics Technology Center, US Army Tank-Automotive Research, Development and Engineering Center (TARDEC) and the Simulation Technology Center (STC), US Army Research Development and

Engineering Command (RDECOM) (formerly the science and technology element of the US Army Simulation, Training and Instrumentation Command (STRICOM)), have worked to create simulation technology that could be embedded into close combat vehicles. TARDEC's interests have been primarily in vehicle workload issues, while STC focused on using embedded simulation for training and mission rehearsal. The two organizations have shared research ideas and products through several years of development. With the advent of the Future Combat System, both programs began to focus their research toward this developing system of systems. As the direction of the research became more aligned, other opportunities to share technology were recognized and pursued.

### **BACKGROUND**

#### **TARDEC**

For FCS the Army needs smaller and lighter combat vehicles offering increased lethality, survivability, and mobility. These requirements are further combined with the need to assimilate and distribute more information to, from, and within the vehicle. To achieve these goals, the Army's future combat vehicles will need highly integrated multi-mission capable crewstations. The Army's move toward a digital battlefield has also created a tremendous need for revolutionary increases in vehicle and command, control, communications, computers and intelligence (C4I) systems performance.

To achieve some of these goals TARDEC is working on the Crew integration and Automation Testbed (CAT) Advanced Technology Demonstration (ATD) to demonstrate a multi-mission capable two-man

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crewstation platform concept. These concept crewstations will be integrated into a C-130-transportable chassis supporting the Army's Objective Force (OF). This program focuses on an improved soldier machine interface (SMI) design using indirect vision driving and automated decision aids, an advanced electronic architecture design/network topology, and embedded simulation. By demonstrating these advanced technologies and other capabilities, the CAT ATD will prove technology readiness to sufficiently transition and integrate hardware and software components into FCS.

CAT ATD uses embedding simulation technologies to reduce crew workload by improving training, virtual battlespace visualization and mission rehearsal. Embedded simulation also has potential for virtual test and evaluation. CAT crewstations have been integrated into a Light Armored Vehicle (LAV) Stryker variant chassis. The CAT ATD has supported the Lead Systems Integrator (LSI) in the area of Unmanned Combat Demonstration (UCD).

The UCD is using the CAT crewstations to control Armed Robotics Vehicles (ARV) reconnaissance variants. The CAT and Robotics Follower (RF) ATD were the closest surrogate programs available to the LSI for the Control Vehicle (CV)/ARV concept. The UCD's main function is to prove validity of the CV/ARV for Increment 1 of FCS. Workload, robotics maturity and functional ability were addressed in the virtual environment and at Ft. Bliss in a field demonstration.

Over a number of years, TARDEC research evolved a significant body of vehicle simulation software known as an Embedded Simulation System (ESS). Operating on vehicle crewstations, this software simulates sensors, weapons and robotic vehicles and provides an interface for the soldier to interact with these simulated systems. Building on an earlier version of the ESS known as Vetronics Technology Testbed (VTT) the CAT ATD ESS configuration operates on two crewstations that have been installed in a LAV vehicle to produce appropriate crew task loading for mission scenarios to test crewstation design and demonstrate unmanned combat.

## RDECOM

In parallel with the TARDEC work, the RDECOM STC has been pursuing a research program targeting embedded simulation technology specifically for training and mission rehearsal applications. The current STC effort, Embedded Combined Arms Team Training and Mission Rehearsal (ECATT/MR) Science and Technology Objective (STO), is researching

embedded simulation technologies for training and mission rehearsal for FCS platforms.

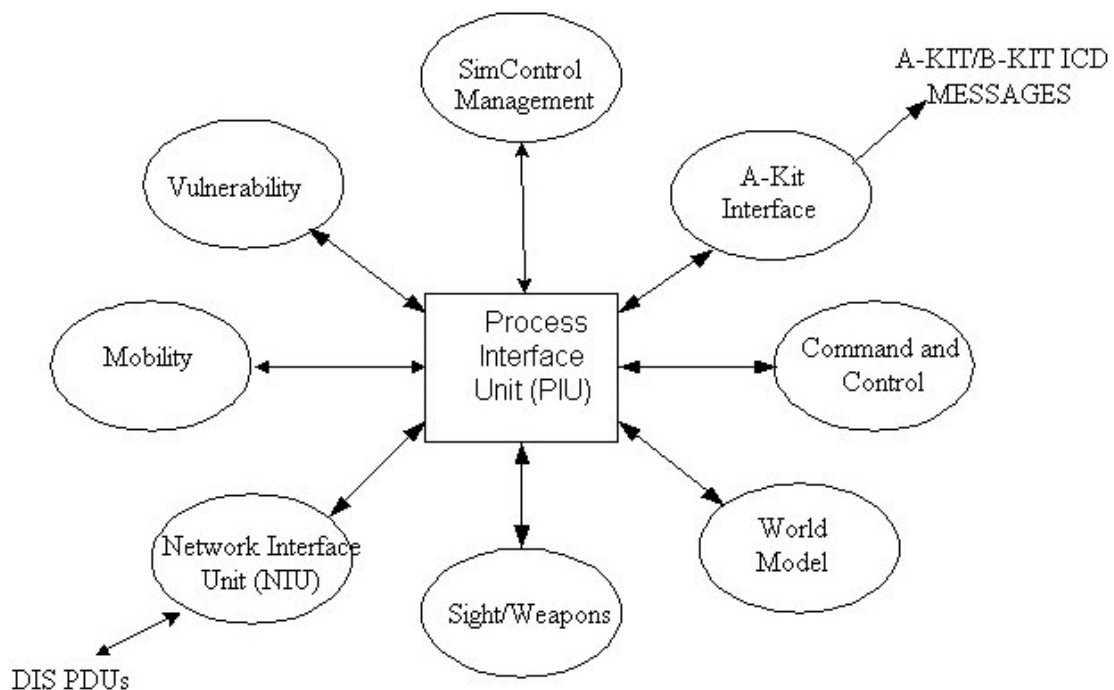
Through a contract with the Institute for Simulation and Training (IST), University of Central Florida, STC built an Embedded Training/Mission Rehearsal (ET/MR) Testbed to integrate and demonstrate various STO technologies. The Testbed consists of two, low cost, man-in-the-loop crewstations representing crew positions in FCS platforms. The ET/MR Testbed crewstation design was patterned after the CAT ATD crewstations, albeit with much less capability and at much lower cost as they did not require the ruggedness nor the fidelity necessary to mount crewstations in an actual vehicle. As a further effort to achieve maximum capability with minimum cost, TARDEC agreed to provide RDECOM with the ESS software from VTT and later from CAT ATD for the ET/MR Testbed.

If successful, the benefits of STC's reuse of the VTT ESS were obvious. TARDEC has invested many person-years of development into the ESS. STC could achieve much greater simulation functionality with its two-person programming staff and avoid significant cost if the ESS would satisfy the simulation needs of the ET/MR Testbed. On the other hand, TARDEC would also benefit from this reuse as STC would provide versions of ESS software back to TARDEC with additional debugging and added functionality.

## VETRONICS TECHNOLOGY TESTBED (VTT)

Before discussing the process of adapting VTT to Testbed use, some understanding of the various components of the VTT software is necessary. The basic architecture consists of an A-Kit representing the vehicle and interfaces to the vehicle, and a B-Kit consisting of the Embedded Simulation System. The major components of the ESS are depicted in Figure 1 and briefly described below.

- PIU (Process Interface Unit) – The sole communication channel between simulation components. It allows multiple programs to interact asynchronously in the overall simulation. PIU generally hides details of where other simulation processes execute and inter-process communication is handled implicitly. All VTT processes use PIU.
- AKITInterface - The peer connection to the vehicle or A-Kit. Provides the indirect abstraction for vehicle resident functions and controls. Vehicle-side messages of interest were incorporated into the host program.



**Figure 1 ESS Software Components**

- **Command and Control (C2)** - Monitors and responds to the AKitInterface for incoming Joint Variable Message Format (JVMF) radio message traffic. This version has scripted response logic. For example, when the A-Kit receives a JVMF Overlay Message, C2 can respond with a Free Text Message ("Roger Over"). A number of JVMF messages were implemented, including Call for Fire Report, Logistics Report, Obstacle Report, Situation Report, Spot Report, Subsequent Adjust, and Threat Warning.

- **World** - The link between the image generation visualization software and the PIU/simulation. Traditionally a single host process is used to drive an image generator, however the VTT architecture uses many individual components to accomplish the host functionality.

- **Sight/Weapons** - Line of sight weapons configuration and control. Contains logic for current weapon orientation, weapon type and round flyout.

- **Network Interface Unit (NIU)** - The link between the One Semi-Automated Forces Testbed (OTB) and the VTT simulation. It uses Distributed Interactive Simulation (DIS) Version 2.04 to relay Protocol Data Units (PDUs) to and from OTB. It uses the OTB libraries for transformations against position, orientation and velocity.

- **Mobility** - Physics model used to navigate virtual vehicles across terrain databases.

- **Vulnerability** - Handles incoming round casualty assessment. Uses a geometry model and OpenGVS software for damage assessment.

- **SimulationControlManagement** - Uses configuration files to locate and start/restart simulation processes. Scripts are executed based on the state of the simulation.

## ADAPTING VTT ESS TO TESTBED USE

The VTT ESS software is functionally robust with a code base estimated at approximately 140,000 lines of code. Since the ET/MR Testbed was to be a scaled down version of TARDEC's testbed, the ET/MR Testbed would need to implement only a portion of the simulation functionality built into the VTT code. The IST Embedded Team also had limited resources, with only one full time software engineer and one part time graduate student researcher, so the possibility of utilizing the entire VTT package was out of reach in the near term. The team followed a piecemeal approach, prioritizing desired functionality, and then focusing effort on the priority packages until the simulation was working as expected.

In March 2002, TARDEC provided IST with the first drop of the VTT ESS. This drop contained a scaled down version of the Process Interface Unit (PIU) with no vehicle functionality. TARDEC refers to this software distribution as the "PIUMinimal" since it is a minimal selection of software required to run the PIU

process. The PIUMinimal is an ideal tool for learning how the PIU operates, and IST used this as an opportunity to understand and exercise the system.

The second software installment was received in June 2002 and contained most of the core VTT source code. Absent from the distribution were vehicle resident software components such as the Map Server that provides 2-dimensional (2D) representation of terrain and all graphic user interfaces (GUI) used in the TARDEC crewstations. Since IST has neither vehicle nor an appropriate platform in which to run vehicle-based software, IST had to "fill in the gaps" where vehicle side software was missing.

The first tasks with the new drop were to evaluate the functionality included in the VTT drop, understand the software and its dependencies, then determine what functionality would be implemented in the ET/MR Testbed. Since there was no vehicle in which the Testbed version of VTT controls could reside, TARDEC provided a test input program called the "TestGUI" that simulated vehicle input and other A-Kit (vehicle-side) messages. Unfortunately the TestGUI program was developed on an SGI platform and used a licensed widget set for which IST had no license. A week was required to port TestGUI to Linux and to convert to an open source widget set. While porting the TestGUI program, the VTT software was updated for a newer Linux distribution that was stable on ET/MR Testbed hardware (RedHat Linux 7.3). This involved modification to some library and API calls as the original VTT operating system was RedHat 6.2.

After several weeks of studying and experimenting with the VTT code, implementation of ownship mobility was set as the initial functional objective. The Mobility and World functions were identified as high priority for this effort and work was initiated that successfully installed these components on the ET/MR Testbed.

After successfully establishing ownship mobility, the next objective involved using Mobility, NIU, AKitInterface and the TestGUI together to put DIS packets on the network. Carmel Applied Technology Inc.'s (CATI) XIG image generator was used to visualize the ownship vehicle and understand the cause-effect relationship between A-kit messages on the TestGUI and the Mobility behavior. The TestGUI program proved a very useful tool for exploration of the A-Kit messages, and lead to the realization that vehicle simulation beyond the TestGUI would be required.

IST developers created a simulated vehicle program to serve as a logical surrogate for the actual vehicle. Using the A-Kit to B-Kit Interface Control Document (ICD) that describes messages between vehicle and ESS, and the example provided by the TestGUI

program, IST implemented the necessary protocol to serve as the behavioral approximation of the vehicle. A control yoke and pedals were implemented as an off-the-shelf solution for vehicle control. Additionally, incoming B-Kit vehicle simulation data was used for graphical display of vehicle datum such as a speedometer, tachometer, voltage gauge, and Global Positioning System (GPS) location. Later instantiations of the simulated vehicle included gear selectors, ordnance selectors, fuel level indicators and target list displays. Future versions of the simulated vehicle will include an object-oriented ground truth state vehicle class for flexibility and upgrade purposes.

The next phase in adapting VTT software was to optimize the World component so that the host processes directly controlled the image generator, rather than it being controlled indirectly with DIS packets. Direct host control of image generators increased frames-per-second performance by 60% and decreased display latency.

In working with the World component it was discovered that many World functions were disabled by the default system state, which is controlled by the Simulation Management component. Since there were no immediate plans for using the Simulation Management component a good deal of time was spent disabling the Simulation Management specific code. This same situation was encountered when integrating the line of sight (LOS) package that controls the turret motion, line of sight weapons, and targeting functions. Again Simulation Management specific code had to be disabled for the system to respond correctly.

After successfully adapting the World component, the ET/MR Testbed had a basic embedded simulation system that could move ownship, employ weapons and sighting systems, and destroy DIS generated entities. The Testbed and ESS were used for demonstrations of STO research at the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC) in December 2002, and again for demonstrations of embedded training technology in the House and Senate Office Buildings in Washington, DC in February 2003.

For a variety of reasons, some original VTT distribution components were left out of the ET/MR Testbed configuration. For example, the Vulnerability component that detects when the ownship has been damaged or killed required a license for OpenGVS that the STC program neither owned nor desired to purchase. C2 and SimulationControlManagement components were not implemented due to time and labor considerations. As program requirements change, these components may be added to the Testbed ESS.

## EXTENSION OF VTT SOFTWARE

In addition to adapting the VTT ESS to Testbed use, IST also added functionality to the ESS.

### AUDIO COMPONENT

The ET/MR Testbed required an audio system. Initial specifications called for a simple set of sounds that would be played in direct response to input events. During the research phase it appeared feasible to implement spatial renderings of most vehicle related sounds and ambient entity noise. Most data required for a reasonably accurate sound component already existed in VTT, and all positional data provided by the Mobility and NIU components was spatial in nature. The VTT PIU component already had some initial high-level work toward a sound system that provided a baseline for development. A very useful audio library called OpenAL was located that is OpenGL compliant and provides tools to render spatialized audio in a way that is independent of the coordinate system unit, rendering sound effects correctly regardless of whether the coordinate system is measured in feet or meters.

One of the issues in implementing spatial audio software is tracking with respect to the listener the location and orientation of the sound generating entities involved in the simulation. The new audio component added an entity class and container for tracking entity location. Another issue concerned rendering sound from too many entities simultaneously because the audio card can handle only a limited number of simultaneous sounds. An algorithm was

developed to determine which entities would be rendered at a given instant. Ownship sounds are given priority and are always rendered. Entities are given priorities such that the closer the entity (if the entity is not dead) the higher the priority. If there are 50 entities within a specific distance, then the  $n$  closest entities (that are still alive) are chosen to render, where  $n$  is the maximum number of audio samples the card can handle minus the number of samples reserved for the ownship. A class hierarchy of sound sources was developed to handle different styles of the audio elements such as instantaneous (cannon firing), or continuous (an engine running). The Close Combat Tactical Trainer (CCTT) sound library was imported and used without resampling. This sound system component was provided back to TARDEC.

### UNMANNED VEHICLE STATUS (UVSTATUS)

One of the objectives of the ET/MR Testbed is to experiment with training for robotics management. However, the VTT software did not have a robotic control component. This component was being added for the CAT ATD but for CAT it would be closely coupled with vehicle software and therefore not useful to the ET/MR Testbed. To functionally create this capability, IST developed a scaled down version of the GUI that TARDEC was developing as the CAT soldier machine interface (SMI). IST considered it important to remain generally consistent with the GUI being developed by TARDEC. Graphics and layouts of CAT SMI specifications were adapted to Testbed use in order to maintain the look and feel of CAT GUI as shown in Figure 2.



Figure 2: Screen Shot of UVStatus Application

The UVStatus component functionality was limited for the Testbed. It serves primarily as a current status display for unmanned vehicles (UVs) controlled by the ownship. Features were developed to allow visualization of sensor imagery from remote air and ground robotic vehicles and to quickly switch between views of the deployed assets. Four levels of zoom and IR features were implemented in the UVStatus application. A robotic vehicle control interface was also added and is addressed in Future Plans. A different robotic vehicle instrument panel was also designed and implemented.

The UVStatus application required a completely new integration with the PIU since no previous component could be leveraged. PIU integration requires a number of modifications to support new processes consisting of approximately 11 different steps as documented in the PIUComm maintenance guide. Additionally, new message types for UV viewpoint manipulation were added, involving modifying the ICD and at least 16 discrete modifications to the PIU core software per message. These modifications are reasonably well documented in the PIUComm maintenance guide. Every major change to the PIU required a recompile of all the other PIU based components in order to link with the latest PIU behavior.

## **TRADE-OFFS**

Earlier paragraphs addressed a number of tradeoffs made during the course of this effort. This included the tradeoffs between labor vs. the number of services that could be implemented and the cost of license vs. loss of functionality. Other tradeoff decisions also affected to final version of the ET/MR capability.

## **VEHICLE VS. NO-VEHICLE - MAP SERVER**

Both VTT and CAT ESS were developed with the objective of operating from crewstations in live vehicles. Their design leveraged vehicle systems and vehicle operating systems, using vehicle components where possible rather than duplicating that capability in VTT and CAT development. As a result some of the software that supports the VTT and CAT ESS is vehicle-based and uses the vehicle's VXWorks operating system. A key issue for RDECOM and IST concerned how to handle vehicle-related software dependencies.

One of IST's major vehicle-related decisions concerned the 2D map provided to crewstation operators. TARDEC uses the VXWORKS-based Map Server to present this 2D map and also as a touch screen input device to direct robotic vehicle movement and other actions. IST elected to use OneSAF Testbed (OTB) Plan View Display for presentation of the 2D

situational awareness information as acquiring VXWORKS for the Map Server was not an option. By using OTB, the ET/MR Testbed gave up some desirable Map Server features such as map symbology. On the other hand, using OTB avoids having to support an additional terrain database format for the Map Server and offers easily magnified visualization of 2D terrain. This was considered a reasonable tradeoff as emerging versions of OTB may accommodate the desired symbology and other applications as discussed later would provide the interface to robotic vehicles.

## **SOLDIER MACHINE INTERFACE**

The GUI supporting soldier-machine interface in VTT is also a vehicle resident software system. This required that IST develop a separate SMI for the Testbed based on an ESS-resident GUI. The resulting ET/MR Testbed SMI generally followed the CAT SMI design, again striving to remain consistent with CAT. The ET/MR Testbed SMI deviates somewhat from CAT in that this SMI supports only the functions needed for the Testbed. As more of the CAT software functionality is added, the SMI will expand accordingly.

## **FUTURE PLANS**

STC and IST continue to pursue integration of other CAT software functionality, such as new models for vehicle and weapons, and the Reconnaissance Surveillance and Target Acquisition (RSTA) component. With TARDEC, STC is also pursuing a joint demonstration of embedded training and mission rehearsal using ECATT/MR STO research products and the CAT vehicle in late FY04.

Using products from an STC robotics STO, modifications are being made to the ESS to support Testbed control of both live and virtual robotic vehicles. In lieu of the CAT robotic control component that is closely coupled with vehicle systems, efforts are underway to integrate the Robotics Multi-Functional Operators Control Unit (OCU). Developed by RDECOM and Unit of Action Maneuver Battle Lab (UAMBL) under STC's Advanced Robotic Simulation STO, OCU integration will expand the PIU process and add various robotic control features to the SMI. Because of differences between OCU and CAT robotic control architectures, this function will not be useful to TARDEC.

Another of the ECATT/MR STO contractors, Stottler Henke Associates, Inc. (SHAI), is developing a prototype Intelligent Tutor oriented to training robotic management at the operator level. Their effort will utilize the robotics OCU in the ET/MR Testbed as the baseline system for tutor research. IST is working with



SHAI to expand the PIU to accommodate the data demands of their Intelligent Tutor processes. TARDEC has expressed interest in using the high level features of this tutor with the CAT ESS and the intelligent tutor will be included as part of a software deliverable to TARDEC.

In another STO effort, United Defense Limited Partners (UDLP) Ground Systems Division is researching embedded training for situational awareness between the FCS Infantry Carrier Vehicle (ICV) and its dismounted infantry. IST will create an ICV version of a Testbed crewstation and modify the current ESS software as necessary to represent FCS ICV functionality. UDLP's situational awareness research products will be integrated into the Testbed for research, evaluation, and demonstration. TARDEC has also expressed interest in this component and it will be included as part of a software deliverable to TARDEC.

Still a third STO contractor, Science Applications International Corporation (SAIC) is researching the use of Force XXI Battle Command Brigade and Below (FBCB2) as a control station for OTB. This work will also be integrated into the Testbed and provided to TARDEC. SAIC is also researching single host architectures for FCS embedded training. If successful, this architecture may replace the current ET/MR Testbed architecture.

## CONCLUSIONS

An embedded simulation system built from VTT ESS as described above is now functional and is running in the crewstations of the RDECOM FCS ET/MR Testbed. So in answer to the title question, no, reusing vehicle simulation software is not "mission impossible". Nor is it an easy task. Adapting any software package to a different use, especially a package as large and complex as VTT, is a meticulous, time-consuming, labor-intensive task. But when the new purpose is as closely matched to the original purpose, as was the case here, it is also a very effective use of resources. Had RDECOM been required to develop the ET/MR Testbed embedded simulation system from scratch, available resources would have been woefully inadequate to develop the level of functionality that exists today based on VTT.

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